Java: class hierarchy, polymorphism

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Programming Language Concepts

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A Java class

- An `Employee` class
- Two private instance variables
- Some constructors to set up the object
- Accessor and mutator methods to set instance variables
- A public method to compute bonus

```
public class Employee{
  private String name;
  private double salary;

  // Some Constructors ...

  // "mutator" methods
  public boolean setName(String s){ ... }
  public boolean setSalary(double x){ ... }

  // "accessor" methods
  public String getName(){ ... }
  public double getSalary(){ ... }

  // other methods
  public double bonus(float percent){
     return (percent/100.0)*salary;
  }
}
```

Subclasses

- Managers are special types of employees with extra features

```
public class Manager extends Employee{
     private String secretary;
     public boolean setSecretary(name s){ ... }
     public String getSecretary(){ ... }
}
```

- `Manager` objects inherit other fields and methods from `Employee`
  - Every `Manager` has a `name`, `salary` and methods to access and manipulate these.
- `Manager` is a subclass of `Employee`
  - Think of subset

Subclasses

- `Manager` objects do not automatically have access to private data of parent class.
  - Common to extend a parent class written by someone else
- How can a constructor for `Manager` set instance variables that are private to `Employee`?
- Some constructors for `Employee`
- Use parent class's constructor using `super`
- A constructor for `Manager`

```
public class Employee{
  ...
  public Employee(String n, double s){
     name = n; salary = s;
  }
  public Employee(String n){
     this(n,500.00);
  }
}
```

```
public class Manager extends Employee{
  ..
  public Manager(String n, double s, String sn){
     super(n,s);   /* super calls
                      Employee constructor */
     secretary = sn;
  }
}
```

Inheritance

- In general, subclass has more features than parent class
  - Subclass inherits instance variables, methods from parent class
- Every `Manager` is an `Employee`, but not vice versa!
- Can use a subclass in place of a superclass
  `Employee e = new Manager(...)`
- But the following will not work
  `Manager m = new Employee(...)`
- Recall
  - `int[] a = new int[100];`
  - Why the seemingly redundant reference to `int` in `new`?
- One can now presumably write
  `Employee[] e = new Manager[100];`

Dynamic dispatch

- `Manager` can redefine `bonus()`

```
double bonus(float percent){
   return 1.5*super.bonus(percent);
}
```

  - Uses parent class `bonus()` via `super`
  - Overrides definition in parent class
- Consider the following assignment

```
Employee e = new Manager(...)
```

- Can we invoke `e.setSecretary()`?
  - `e` is declared to be an `Employee`
  - Static typechecking — `e` can only refer to methods in `Employee`
- What about `e.bonus(p)`? Which `bonus()` do we use?
  - Static: Use `Employee.bonus()`
  - Dynamic: Use `Manager.bonus()`
- Dynamic dispatch (dynamic binding, late method binding, . . .) turns out to be more useful
  - Default in Java, optional in languages like C++ (`virtual` function)

Polymorphism

- Every `Employee` in `emparray` "knows" how to calculate its `bonus` correctly!
- Recall the event simulation loop that motivated Simula to introduce objects
- Also referred to as runtime polymorphism or inheritance polymorphism
- Different from structural polymorphism of Haskell etc — called generics in Java

```
Employee[] emparray = new Employee[2];
Employee e = new Employee(...);
Manager m = new Manager(...);

emparray[0] = e;
emparray[1] = m;

for (i = 0; i < emparray.length; i++){
  System.out.println(emparray[i].bonus(5.0))
}
```

```
Q := make-queue(first event)
repeat
  remove next event e from Q
  simulate e
  place all events generated
```

Functions, signatures and overloading

- Signature of a function is its name and the list of argument types
- Can have different functions with the same name and different signatures
  - For example, multiple constructors
- Java class `Arrays` has a method `sort` to sort arbitrary scalar arrays
- Made possible by overloaded methods defined in class `Arrays`

```
double[] darr = new double[100];
int[] iarr = new int[500];
...
Arrays.sort(darr);
  // sorts contents of darr
Arrays.sort(iarr);
  // sorts contents of iarr
```

```
class Arrays{
  ...
  public static void sort(double[] a){..}
     // sorts arrays of double[]
  public static void sort(int[] a){..}
     // sorts arrays of int[]
  ...
}
```

Functions, signatures and overloading

- Overloading: multiple methods, different signatures, choice is static
- Overriding: multiple methods, same signature, choice is static
  - `Employee.bonus()`
  - `Manager.bonus()`
- Dynamic dispatch: multiple methods, same signature, choice made at run-time

```
double[] darr = new double[100];
int[] iarr = new int[500];
...
Arrays.sort(darr);
  // sorts contents of darr
Arrays.sort(iarr);
  // sorts contents of iarr
```

```
class Arrays{
  ...
  public static void sort(double[] a){..}
     // sorts arrays of double[]
  public static void sort(int[] a){..}
     // sorts arrays of int[]
  ...
}
```

Type casting

- Consider the following assignment

  ```
  Employee e = new Manager(...)
  ```

- Can we get `e.setSecretary()` to work?
  - Static type-checking disallows this
- Type casting — convert `e` to `Manager`

  ```
  ((Manager) e).setSecretary(s)
  ```

- Cast fails (error at run time) if `e` is not a `Manager`

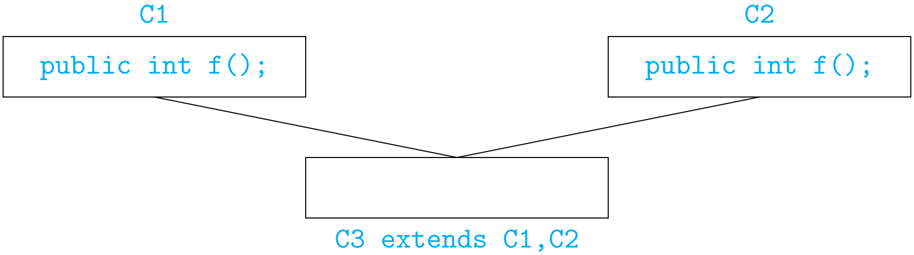
- Can test if `e` is a `Manager`

  ```
  if (e instanceof Manager){
    ((Manager) e).setSecretary(s);
  }
  ```

- A simple example of reflection in Java
  - "Think about oneself"
- Can also use type casting for basic types

  ```
  double d = 29.98;
  long nd = (long) d;
  ```

Multiple inheritance



- Can a subclass extend multiple parent classes?
- If `f()` is not overridden, which `f()` do we use in `C3`?
- Java does not allow multiple inheritance
- C++ allows this if `C1` and `C2` have no conflict

Java class hierarchy

- No multiple inheritance — tree-like
- In fact, there is a universal superclass `Object`
- Useful methods defined in `Object`

```
public boolean equals(Object o)  // defaults to pointer equality

public String toString()         // converts the values of the
                                 // instance variables to String
```

- For Java objects `x` and `y`, `x == y` invokes `x.equals(y)`
- To print `o`, use `System.out.println(o+"");`
  - Implicitly invokes `o.toString()`

Java class hierarchy

- Can exploit the tree structure to write generic functions
  - Example: search for an element in an array

```
public int find (Object[] objarr, Object o){
  int i;
  for (i = 0; i < objarr.length(); i++){
      if (objarr[i] == o) {return i};
  }
  return (-1);
}
```

- Recall that `==` is pointer equality, by default
- If a class overrides `equals()`, dynamic dispatch will use the redefined function instead of `Object.equals()` for `objarr[i] == o`

Overriding functions

- For instance, a class `Date` with instance variables `day`, `month` and `year`
- May wish to override `equals()` to compare the object state, as follows

```
public boolean equals(Date d){
  return ((this.day == d.day) &&
          (this.month == d.month) &&
          (this.year == d.year));
}
```

- Unfortunately,
  `boolean equals(Date d)`
  does not override
  `boolean equals(Object o)`!

- Should write, instead

```
public boolean equals(Object d){
  if (d instanceof Date){
    Date myd = (Date) d;
    return ((this.day == myd.day) &&
            (this.month == myd.month)
            (this.year == myd.year));
  }
  return(false);
}
```

  - Note the run-time type check and the cast

Overriding functions

- Overriding looks for "closest" match
- Suppose we have `public boolean equals(Employee e)` but no `equals()` in `Manager`
- Consider

```
Manager m1 = new Manager(...);
Manager m2 = new Manager(...);
...
if (m1.equals(m2)){ ... }
```

- `public boolean equals(Manager m)` is compatible with both `boolean equals(Employee e)` and `boolean equals(Object o)`
- Use `boolean equals(Employee e)`

Subclasses, subtyping and inheritance

- Class hierarchy provides both subtyping and inheritance
- Subtyping
  - Capabilities of the subtype are a superset of the main type
  - If `B` is a subtype of `A`, wherever we require an object of type `A`, we can use an object of type `B`
  - `Employee e = new Manager(...);` is legal
- Inheritance
  - Subtype can reuse code of the main type
  - `B` inherits from `A` if some functions for `B` are written in terms of functions of `A`
  - `Manager.bonus()` uses `Employee.bonus()`

Subtyping vs inheritance

- Recall the following example
  - `queue`, with methods `insert-rear`, `delete-front`
  - `stack`, with methods `insert-front`, `delete-front`
  - `deque`, with methods `insert-front`, `delete-front`, `insert-rear`, `delete-rear`
- What are the subtype and inheritance relationships between these classes?
- Subtyping
  - `deque` has more functionality than `queue` or `stack`
  - `deque` is a subtype of both these types
- Inheritance
  - Can suppress two functions in a `deque` and use it as a `queue` or `stack`
  - Both `queue` and `stack` inherit from `deque`

Subclasses, subtyping and inheritance

- Class hierarchy represents both subtyping and inheritance
- Subtyping
  - Compatibility of interfaces.
  - `B` is a subtype of `A` if every function that can be invoked on an object of type `A` can also be invoked on an object of type `B`.
- Inheritance
  - Reuse of implementations.
  - `B` inherits from `A` if some functions for `B` are written in terms of functions of `A`.
- Using one idea (hierarchy of classes) to implement both concepts blurs the distinction between the two

Modifiers in Java

- Java uses many modifiers in declarations, to cover different features of object-oriented programming
- `public` vs `private` to support encapsulation of data
- `static`, for entities defined inside classes that exist without creating objects of the class
- `final`, for values that cannot be changed
- These modifiers can be applied to classes, instance variables and methods
- Let's look at some examples of situations where different combinations make sense

public vs private

- Faithful implementation of encapsulation necessitates modifiers `public` and `private`
  - Typically, instance variables are `private`
  - Methods to query (accessor) and update (mutator) the state are `public`
- Can `private` methods make sense?
- Example: a `Stack` class
  - Data stored in a private array
  - Public methods to push, pop, query if empty

```
public class Stack {
  private int[] values; // array of values
  private int tos;      // top of stack
  private int size;     // values.length

  /* Constructors to set up values array */

  public void push (int i){
    ....
  }

  public int pop (){
    ...
  }

  public boolean is_empty (){
    return (tos == 0);
  }
}
```

`private` methods

- Example: a `Stack` class
  - Data stored in a private array
  - Public methods to push, pop, query if empty
- `push()` needs to check if stack has space
- Deal gracefully with stack overflow
  - `private` methods invoked from within `push()` to check if stack is full and expand storage

```
public class Stack {
  private int[] values; // array of values
  private int tos;      // top of stack
  private int size;     // values.length

  /* Constructors to set up values array */

  public void push (int i){
    ....
  }

  public int pop (){
    ...
  }

  public boolean is_empty (){
    return (tos == 0);
  }
}
```

Accessor and mutator methods

- Public methods to query and update private instance variables
- `Date` class
  - Private instance variables `day`, `month`, `year`
  - One public accessor/mutator method per instance variable
- Inconsistent updates are now possible
  - Separately set invalid combinations of `day` and `month`
- Instead, allow only combined update

```
public class Date {
  private int day, month year;

  public void getDay(int d) {...}
  public void getMonth(int m) {...}
  public void getYear(int y) {...}

  public void setDay(int d) {...}
  public void setMonth(int m) {...}
  public void setYear(int y) {...}
}
```

```
public class Date {
  private int day, month year;

  public void getDay(int d) {...}
  public void getMonth(int m) {...}
```

static components

- Use static for components that exist without creating objects
  - Library functions, main(), ...
  - Useful constants like Math.PI, Integer.MAX_VALUE
- These static components are also public
- Do private static components make sense?
- Internal constants for bookkeeping
  - Constructor sets unique id for each order

```
public class Order {
  private static int lastorderid = 0;

  private int orderid;
  ....

  public Order(...) {
    lastorderid++;
    orderid = lastorderid;
    ...
  }
```

- lastorderid is private static field
- Common to all objects in the class
- Be careful about concurrent updates!

final components

- `final` denotes that a value cannot be updated
- Usually used for constants (`public` and `static` instance variables)
  - `Math.PI`, `Integer.MAX_VALUE`
- What would `final` mean for a method?
  - Cannot redefine functions at run-time, unlike Python!
- Recall overriding
  - Subclass redefines a method available with the same signature in the parent class
- A `final` method cannot be overridden